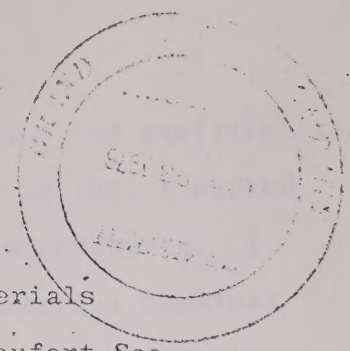




Spills of Oil and Hazardous Materials  
in the Mackenzie Valley, Delta and Beaufort Sea

~~First Draft, January 16, 1976~~

MAKENZIE VALLEY PIPELINE INQUIRY  
EXHIBIT NO. 123 A.D. April 1976  
Yellowknife, N.W.T.  
Mr. Bayly

EVIDENCE OF  
Donald Mackay  
FOR THE  
THE MACKENZIE VALLEY PIPELINE  
INQUIRY  
APPEARING FOR  
COPE JANUARY 1976

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Mr.  
Dear Commissioner:

First I would like to outline my experience and qualifications.

*the University*  
After graduating with a Ph.D. in Glasgow in 1961 I worked at Toronto on hydrocarbon reactions at high temperatures. I returned to the United Kingdom to work with Imperial Chemical Industries on Hydrocarbon reactions mainly in the liquid state at lower temperatures and on separation techniques such as distillation. In 1965 I returned to Toronto and obtained a position as *Island* associate professor in the Department of Chemical Engineering and Applied Chemistry. Later I became Associate Professor and also Associate Director of the Institute for Environmental Studies at the University of Toronto. I continued my research interest in hydrocarbons and in particular on the behaviour and effects of hydrocarbons when spilled in the environment. My major Arctic work commenced in 1971 when we obtained a 3 year contract with the Environmental-Social Program Northern Pipelines which involved spilling quantities of crude oil and examining the physical and biological effects at locations such as Norman Wells, Inuvik, Tuk, Richards Island, the Mackenzie River and in cooperation with Environment Canada on a lake in the Mackenzie Delta. The results of these studies have been published by the Environmental-Social Program. I also participated as a consultant for the NORCOR in their studies of oil spills in shore fast ice at Cape Parry in 1974-75. I have done, and am continuing, coldroom





studies of the behaviour of oil in ice. I recently completed a review of the behaviour, effects and the possibilities of clean up of oil spills from offshore drilling incidents in ice-infested waters such as the Beaufort Sea. I have obtained research funding from agencies such as the Environmental Protection Service and PACE (Petroleum Association to Conserve the Canadian Environment) to undertake work on aspects of oil spill and clean up. The adaptation of oil spill clean up systems used in temperate climates for use in cold climates and development of new technologies specific to cold climates is an area of current interest. A list of publications and biographical data are appended.

The issue of concern here is spills of oil and other hazardous materials which may result from construction, operation and exploration activities of the petroleum industry in the Mackenzie Valley Delta and Beaufort Sea. In my opinion one can approach this issue by breaking it down into 5 aspects. Let me state this approach, present my opinions, and defend or justify them later.

1. Prevention.

<sup>THIS Inquiry</sup>  
The inquiry can play an important role in requiring <sup>but</sup> appropriate measures be taken to prevent spills. Many have been discussed in early <sup>in</sup> evidence, for example storage of fuels,



lubricants or antifreeze solutions, and diking procedures round tanks. In my opinion if procedures as recommended in the Mackenzie Valley Pipeline Assessment report of the PAAG are followed then damage should be acceptably small. Surveillance or inspection during construction is desirable. Another more serious problem is that of crude oil spills during exploration, production or transportation of oil from this region. There is no pipeline application as yet although there may be offshore drilling in 1976.

## 2. Spill Predictions

Despite preventative measures there will be spills. I believe that an estimate must be prepared of the probably<sup>e</sup> spill frequency, chemical type, volumes, locations and seasons for both oil and other substances. This is admittedly difficult but does provide a perspective on the magnitude of the problem. Even an approximate estimate is better than no estimate. I will give some such estimates later.

## 3. Physical Behaviour.

Using the typical spill predictions, an estimate should be made of the spills physical behaviour, for example its area of spread, penetration into soil or ice and effects on permafrost. This requires research programs, some of which have been done and some not. This is a necessary prerequisite to any biological or ecological assessment.





#### 4. Other Effects

Based on the physcial behaviour the biological, ecological, social, economic and other effects can be estimated. That is, the total impact examined. This I am not competent to undertake and will not discuss in this evidence.

#### 5. Clean up

It is desirable to develop the capability of cleaning up the spill and restoring the area as quickly as possible to its original state. This <sup>mitigates</sup> ~~insitigates~~ the impact of the spill. This has several aspects, equipment, trained operators, logistical support and the necessary background research and development. I will try to demonstrate that while some temperate climate technology can be used in the Arctic much can not, and could indeed do more harm than good. To my knowledge there has been no active program of research and development to develop cold climate clean-up technology.

Having outlined the approach let me return and discuss each aspect separately.



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## PREVENTION

I believe that prevention has to be built into the design and operating and construction procedures and that the only effective method of ensuring that appropriate preventative measures are taken is by a detailed examination and inspection of all aspects of operations ranging from welding to storage of fuel<sup>S</sup>, to disposal of methanol antifreeze solutions, to <sup>W</sup>blow-out preventions during drilling. I believe that there is a need for effective inspection because it is human nature to take risks and short cuts when one is stressed by tight construction schedules or adverse weather or physical tiredness. This inspection can only be done by technically competent personnel with adequate authority.

In areas of particular biological, social or aesthetic importance such as wild fowl nesting grounds, fish spawning grounds or close to human settlements extreme measures must be taken to prevent oil<sup>pollution</sup> spills by over-designing facilities, by very careful surveillance, <sup>and</sup> as far as is possible, means should be sought to control the ~~oil~~<sup>material</sup> when spilled by previously designed topography for example, careful contouring of drainage <sup>around pipelines</sup> ditches and provision of diked areas. This is essentially an extension to pipeline construction of the established principle of diking of storage facilities.

For offshore exploration and production I believe it would be very desirable for permanent high durability booms to be developed which could contain spilled oil.





## SPILL PREDICTIONS

For fuels, lubricants etc. the amount handled obviously provides an upper limit to the amount which can be spilled. In practice I believe that it is possible to estimate that, for example x percent of the fuel used will be spilled. I have no knowledge of the value of x but I suspect that it will lie between about 0.2% and 2%. It would be valuable to have data from the Alyeska Pipeline on their experience in this regard. Such estimates could give an approximate indication of the number of spills of fuel etc. and the average volume. I recommend that Alyeska data be sought.

The major sources of oil spills are crude oil itself (which may be produced in the region, and transported by pipeline south to Alberta) and oil products (mainly fuels) used for transportation and heating purposes. It is from the latter that most spills in the Arctic have historically occurred and there is every reason to believe that such spills will continue. Crude oil spills may also occur from offshore drilling activities in the Beaufort Sea region. The most serious incidents are likely to be oil pipeline ruptures, failure of large storage tanks, and offshore blowouts.

Dealing first with oil pipelines, in the period 1968 to 1974 inclusive there was a total of 575 oil pipeline failures *in Canada* or an average of 82 per year (Canadian Petroleum Association 1975). The major causes were corrosion, failure of welds, and equipment such as bulldozers rupturing the line. During the period





1968 to 1974 there <sup>was</sup> ~~has been~~ an average failure rate of 4.7 failures per thousand miles of pipeline. During years 1971 to 1974 for every million barrels of oil produced 130 <sup>barrels</sup> have ~~were~~ ~~been~~ spilled, <sup>thus</sup> ~~to~~ put this in perspective, if 1 million barrels per day <sup>were</sup> was ultimately to be transported from the Arctic this would indicate a spill rate of about 130 barrels per day or nearly 50,000 per year. In practice, I would expect <sup>as a result of</sup> about half this rate or about 25,000 barrels per year, <sup>^</sup> better current pipeline construction practices. Another estimate by Mackay, Charles and Phillips (1974) was for 2 major spills per year north of 60° with an average volume of 10,000 barrels which is in good agreement.

Ross (1975) for example lists 16 significant spills of average volume 12,300 gallons in the Arctic during 1971 and 1972. Environment Canada has completed detailed spill statistics.

During offshore activities it has been estimated (National Academy of Sciences 1975) that during production in 1971 of 3200 million barrels some 0.004% was lost in minor spills and 0.014% in major spills of more than 50 barrels. This corresponds to a total of about 180 barrels per day or <sup>65000</sup> about 65 barrels per year at a production rate of 1 million barrels per day.

Spill incidents from exploratory drilling are more difficult to predict however a recent analysis by Kash <sup>over 11,000</sup> et al (1972) suggests that for the <sup>^</sup> 20,000 wells drilled until 1973 <sup>2</sup> there were <sup>37</sup> ~~47~~ blowout incidents including <sup>3</sup> major oil spills and 15 total releases of oil. One can apply a factor

(i.e. greater than 10,000 barrels)

all  
ways to  
get better  
data



to this frequency of failure rate leading to very subjective estimate of the probability of an oil spill. This has been

estimated as high as one percent (Greene and Mackay 1976) *including all phases of exploration and production, (which could involve several hundred wells)* and would correspond to possibly two spills in the Beaufort Sea during the entire development of the basin with about a 1

in 4 probability of a major spill. The pattern of the spillage is likely to be one or two substantial spills and a larger number of small less significant spills. In a "worst case" spill one would expect a discharge rate of the order of 1,000 barrels per day for a period of months with volumes as high as 100,000 barrels being released.

In summary, I believe that during full oil production there could be a release of about 90,000 barrels of oil per year in the region consisting of a few large incidents each year and a number of small incidents. Another approach is that of the 9.9 billion barrels of recoverable oil believed to be in the Mackenzie Delta basin (Canadian Society of Petroleum Geologists 1972) about 0.02% or 2 million barrels would be spilled, possibly over a 25 year period giving about 80,000 barrels per year. *These spill volumes could be prorated down to lower production rates.*

Prediction of Physical Behaviour

A thorough understanding of the physical behaviour of the oil, *i.e.* which type of oil reaches which location in what quantities at what time of year with what thickness and how fast it evaporates, dissolves, weathers etc. is important as a prerequisite to understanding the biological, ecological and microbiological behaviour of the oil and its effects. The feasibility of clean-up is also influenced by





factors such as the state of the oil, the area affected by the oil spill and any fire hazard.

Although there is a great deal of experience with oil spills in more temperate climates there are 3 reasons that Arctic spills may be significantly different and thus require special study and research.

First, when oil is spilled it is subject to a number of physical <sup>and</sup> chemical processes collectively termed "weathering".

This includes dissolution, evaporation, microbial action, dispersion and oxidation. It is generally accepted that these processes take place more slowly under cold climate conditions. The processes tend to cause a reduction in oil toxicity i.e. fresh oil is more toxic than weathered oil.

As a result the period during which the oil may be toxic will be longer in an Arctic environment. In simple terms the toxic components are better preserved. Second, the prevalence of ice during much of the Arctic year raises the complex issue of the interaction of oil with ice, a problem relatively less common in the South. Third, the terrestrial aquatic and marine environments of the Arctic are substantially different in both physical and biological characteristics (an example being the presence of permafrost).

Thus, oil can be expected to behave differently in the Arctic environment and produce different biological and ecological

effects. *Even within the Arctic region in question there are varying conditions,*

*especially in regard to location and weather.* The behaviour of an oil spill will change accordingly.



I believe that five spill locations must be considered, (i) spills in terrestrial regions, (ii) spills into lakes or ponds mainly in the tundra region, (iii) spills into rivers, (iv) spills in the Mackenzie Delta and (v) spills in the Beaufort Sea under various conditions of ice cover. These locations differ markedly depending on the season. In the interest of simplicity three seasons can be considered, winter which is about 60% of the year, the spring thaw which may be about 5% and the summer which is a remaining 35%. This approach has been discussed in more detail by Mackay (1975). It is possible to construct a matrix of 5 locations and 3 seasons and examine the possibilities of a spill in each of the 15 categories. Rather than discuss all of the elements in this matrix the more important ones can be selected and discussed.

#### (i) Terrestrial Spills

The greatest understanding of Arctic oil spills exists for terrestrial spills. Most of the work was undertaken as part of the Environmental-Social Program - Northern pipelines <sup>the physical work</sup> and has been published in a series of reports by Mackay, Charles and Phillips. The physical behaviour of the oil is fairly well understood and it is estimated that the largest spill could cover an area of 16,000 square metres or 4 acres to as high as 300,000 square metres or 72 acres with the average being about 30,000 square metres or about 7 acres. The average spill will probably be about one quarter this size and would cover about 2 acres. This area would be very unsightly, would be completely <sup>e</sup> devastated by oil and would take many years to restore. The impact would





be smallest in winter.

(ii) Lake Spills

~~Could you describe our understanding of lake spills?~~

Lake spills are also fairly well understood mainly because they are similar in characteristics to spills in temperate regions except of course that the period of ice cover is longer. The physical behaviour is fairly predictable and in some respects this may be the most favourable spill condition provided that oil is prevented from leaving the lake. The lake will naturally contain the oil but will of course be completely devastated. *also*

(iii) River Spills

River spills are poorly understood. I know of only two research programs which have taken place one which is largely biological in character (Snow, 1975) and one by Mackay, Charles and Phillips (1975). The general conclusion from the latter was that when oil enters the Mackenzie River it will be totally uncontrollable and its behaviour unpredictable. This movement will be subject to wind and current action which are very specific to the location *to* the spill and the time. Much of the oil will probably become dispersed in the water column and be carried downstream and into the Beaufort Sea. Much will be deposited on the banks and on the bottom where it may have severe biological effects.

(iv) Delta Spills

~~What about the Delta?~~ The Mackenzie Delta is a unique physical and biological environment. Snow and Rosenberg (1974) have reported information on the behaviour of oil spills on two Mackenzie Delta lakes *made* during the summer.



There is a possibility that oil spilled in this region during a period of high water could be trapped in the delta lakes and have a profound effect during the subsequent summer.

### Beaufort Sea Spills

The major experimental work has been the research program undertaken at Cape Parry as part of the Beaufort Sea study. This involved a series of spills under controlled conditions under shorefast ice close to shore. One additional spill was undertaken in offshore ice about 15 miles north of Cape Parry in which there was a current under the ice sheet. To my knowledge there have been no experimental spills during <sup>the</sup> summer in the Beaufort Sea <sup>or</sup> in the shear zone where drilling is proposed for 1976. I believe that a scenario of an oil spill is being produced as part of the Beaufort Sea program and this will give a more complete and accurate picture of the impact of a spill in this region. The behaviour of a summer spill on ice-free water is fairly predictable from the experience of spills in southern waters.

Some of the aspects of the behaviour of oil under ice have been described by Greene and Mackay (1976) but more detailed information is expected to be forthcoming from the Beaufort Sea study.

The general picture which emerges is that oil from a blowout at the sea bottom will rise in a plume of oil droplets of diminishing size which will impinge on the water-air surface <sup>or</sup> of the water-ice surface and spread laterally and particularly in a down-current direction.





Most of the oil will reach the surface and coalesce to form a slick. Much may be retained as particulates in the water column and some will be sedimented to the bottom where it could subsequently interfere with benthic biological processes. The oil will rapidly cool during its rise in the water column. If the spill occurs during the period of ice growth (i.e. most of the winter) then the oil will become locked or sandwiched into the ice and will remain essentially unweathered and well preserved until the release in the spring. First year ice is fairly porous and there is a possibility that the oil will penetrate to the surface particularly during thaw. Since oil has a much lower albedo than snow or ice its presence at the surface during the spring period will have a profound effect on the melting rate. This has been observed for terrestrial spills on snow.

#### Fire Hazards

Oil is a very hazardous substance and when spilled in the environment can give rise to flammable or explosive concentration of vapour. There may be therefore a severe fire or explosion hazard particularly under calm atmospheric conditions as occur frequently in the Arctic winter. If a major oil spill occurs close to a human settlement or road then there could be a considerable danger to the local population. There may be in addition a release of toxic hydrogen sulphide gas. Since about 15% of all pipeline ruptures are caused by equipment accidentally rupturing the line it would seem appropriate to locate any oil pipeline well away from human activity. This would have the effect of reducing the possibility of such incidents and



reducing the hazards to humans from pipeline ruptures.

In summary there is a good understanding of the behaviour of terrestrial spills and lake spills. As for river spills we understand them ~~to the extent that their~~ behaviour is almost completely unpredictable and very specific to the spill site. The Beaufort Sea study has provided a great deal of information on shorefast ice spills. We are very ignorant about the behaviour of massive spills in the delta or in the shear zone or on pack ice.

There is no substitute for spilling large quantities of oil in the environment in order to determine the behaviour and effects of that oil. The minimum spill size has to be about 30 barrels or one thousand gallons in order to obtain meaningful scientific data.

#### Cleanup

It is generally accepted that in the event of an oil spill incident the best initial response <sup>is</sup> to try to contain the oil in as small an area as possible and in particular, prevent oil from reaching flowing water. This containment phase is normally accomplished by booms on water or by constructing dams or barriers on land. The second phase is the removal of as much oil as possible from the spill site by hand or by oil recovery devices such as skimmers. When the bulk of the oil is removed by physical or mechanical means the final stage is restoration in which the uncollected oil is rendered less harmful by natural processes such as microbial degradation but possibly assisted <sup>on land</sup> by fertilizing. As a result of undertaking oil spills in the Arctic and observing spills in ice conditions





it is my belief that some clean up methods traditionally developed for temperate water and land environments are totally unsuitable for the Arctic environment, and that a specific clean up technology will have to be developed for the Arctic environment.

In a review of clean up of terrestrial spills, Mackay and Greene (1975) concluded that burning and diking the two most common methods of clean up in the south are inappropriate for Arctic conditions particularly on permafrost. These techniques could expose areas of permafrost, possibly leading to subsidence. They made suggestions for alternative methods of containment and recovery. To my knowledge no research at all has been undertaken on clean up under these conditions. Some work on the effect of fertilizers on recovery rates has been undertaken. The use of introduced bacteria with a specific capability for consuming oil is not favoured. The general opinion appears to be that the best strategy for cleaning up a terrestrial Arctic spill is to carefully remove ponded oil and leave the remaining oil alone and avoid undue activity in the area. Burning may be desirable under certain conditions where the soil is protected as a result of the presence of underlying ice. It is presently impossible to remove impregnated oil from terrain without mechanically removing the contaminated soil.

For lakes southern technology can probably be translated for Arctic conditions very effectively even in winter. Technology for the containment of oil spills under ice is still in its infancy. For rivers it is accepted that



oil on flowing water at a velocity of greater than about 1 knot is almost completely uncontrollable. There is some possibility that the oil could be diverted to the side of the river by angled booms. However, in turbulent waters even this is impossible. In view of the presence of fast flowing rivers in Canada it would appear that this is an area of particular Canadian concern.

The Delta is a mixed terrestrial and aquatic situation in that there is a possibility of recovering a fair fraction of the oil which reaches quiescent <sup>weather locations</sup> conditions. It should be noted that there is a Mackenzie Delta Protection Unit which is equipped with oil spill clean up equipment.

The issue of containment <sup>and</sup> the recovery of oil in the Beaufort Sea study has been the subject of an intensive study in the Beaufort Sea program. I have not had the opportunity of reading the final reports. The consensus of opinion appears to be that a spill from an offshore drilling incident would be almost totally uncontrollable. The only satisfactory method of destroying oil is by burning but it is not known what fraction of the oil could be safely subjected to burning. Certainly the longer the oil weathers and spreads the less likely the feasibility of burning becomes. With present technology it is probably impossible to contain more than a small fraction of the oil with booms and only under very calm conditions would oil spill recovery equipment operate. If the spill is in ice conditions, recovery is probably nearly impossible with burning the only possibility. // Dispersants (detergent of surface active compounds which cause oil to emulsify) are often advocated





for oil clean up conditions. Essentially they break the oil slick up into a large number of minute droplets which may be subject to faster degradation and wider dispersal. It is noteworthy that dispersants are proposed for oil spill incidents from offshore activities in the North Sea. I believe that dispersants may have a role to play in the Mackenzie River Delta and Beaufort Sea situation, however, the use of such dispersants must be carefully considered in advance since they may have adverse effects by subjecting biota to higher concentrations of oil than would normally occur. Their use may be justified in situations such as an oil slick advancing on a colony of nesting or resting wild fowl or for cleaning oil from ice leads.

Since the Torrey Canyon incident there has been considerable amount of research throughout the world on oil containment, recovery, dispersion and disposal. Most has been done in the United States and the U.K. However, there has been some Canadian work notably on booms in Vancouver. It is my conviction that Canada should seek to exploit to the maximum extent possible the expertise which has been built up abroad in oil spill clean up but that Canada must mount its <sup>own</sup> ~~own~~ program for oil spill control for those conditions which are specific to the Canadian environment. It is increasingly obvious that the Arctic will be the source of much of Canada's future oil. Thus development of clean-up capabilities for the Arctic environment should receive a high priority. The response of Environment Canada in this regard has been disappointing. Development of oil spill clean up measures for Arctic and ice-infested <sup>conditions</sup> ~~conditions~~ has been



virtually non existent and to my knowledge there are no immediate plans to change this situation. After the "Arrow" tanker incident at Chedaducto Bay, those responsible for clean up were required to show extraordinary ingenuity in devising clean up methods. There is no excuse for requiring this degree of ingenuity to be displayed in ~~the Arctic~~ <sup>in the Arctic</sup> ~~there~~ <sup>instead</sup> is doubt that it would be possible to display this ingenuity. The low population density and the cold climate will severely impede the clean up effort and a high degree of preparedness is essential. // I have emphasized so far the effects of massive spills of oil but I would like to end by considering the continual emission of small quantities of oil into the environment of this region.

The chronic problem of long term low-level emission of hydrocarbons is less spectacular <sup>than</sup> ~~as the~~ spill incidents but possibly as important in the long term. In the south such emissions from refineries or industrial facilities are normally well dispersed and degraded in <sup>the</sup> aquatic environment and appear ~~not~~ <sup>few</sup> to cause little problems. However, concentrations of hydrocarbons as low as about 50 parts per billion may have subtle biological effects, for example upsetting reproduction processes. There is a possibility that oil may build up in food chains. Certain species may be particularly susceptible at critical stages of their life. There is thus concern that the introduction of foreign chemical compounds even in small quantities into the environment may harm ecosystems and ultimately ourselves.

I can best answer this by quoting a National Academy





of Sciences publication (1975) which concluded,

"The oceans have considerable ability to purify themselves by biological and chemical actions.

A basic question that remains unanswered is,

"At what level of petroleum hydrocarbon input to the ocean might we find irreversible damage.

occurring?"

The sea is an enormously complex system about which our knowledge is very imperfect. The ocean may be able to accomodate petroleum hydrocarbon inputs far above those occurring today. On the other hand, the damage level may be within an order of magnitude of present inputs to the sea. Until we can come closer to answering this basic question it seems wisest to continue our efforts in the international control of inputs and to push forward research to reduce our current level of uncertainty.

I would like to suggest that there is a real possibility that the Arctic Freshwater and Marine Environments may have a lower capability to tolerate inputs of hydrocarbons and other hazardous chemicals than temperate environments, because degradation rates are slower and biota may be more vulnerable. Our degree of understanding of the Arctic aquatic and marine environments is very much poorer than that of temperate environments. If the Arctic environment is more vulnerable and less understood I believe that it is fitting that we should be prudent, proceed with considerable caution taking the utmost care to prevent discharges of oil and other hazardous chemicals



into that environment, and err on the side of safety.

I would hope that this Inquiry would recommend that such discharges be reduced to a minimum by an effective prevention effort; that we should seek to improve our understanding of the physical biological, social and economic effects of oil spills before oil development starts; and recognizing that spills are inevitable we develop a specifically Canadian Arctic capability to contain, control clean up and restore oil contaminated environments.



